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PARTIALLY BRIQUETTING COKE OVEN CHARGES USING SINGLE WESTERN CANADIAN COALS

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by

J.T. Price and J.F. Gransden

ABSTRACT

Western Canadian coking coals are exported primarily to the Japanese market which produces much of its metallurgical coke by an adaptation of conventional cokemaking technology in which a portion of the coal charged to their coke ovens is briquetted. To explore the suitability of western Canadian coals to this technology high, medium and low volatile coals were each carbonized conventionally and 30% partially briquetted at two coking rates in CANMET's 460-mm test oven.

Results showed all 3 ranks of western Canadian coals tested were particularly suited to partial briquetting technology. Coke quality as measured by the ASTM stability factor improved more by partially briquetting the coals of higher rank, with coke from the low volatile coal improving about 12 ASTM stability units. ASTM hardness, JIS tumbler and coke strength after reaction results also improved for cokes made from partially briquetted charges. Coke quality deteriorated very slightly at a higher flue temperature and coking rate. Only the low volatile coal produced excessive wall pressures when partially briquetted.

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INTRODUCTION

CANMET has carried out several pilot-scale investigations on the partial briquetting of coke oven charges. The majority of the investigations have utilized the low inert Appalachian type coals that are readily accessible to the Canadian steel producers in central Canada. Studies have shown that coke made from coal blends used by Canada's four major steel producers can be improved by 2 to 6 ASTM stability units from that of conventional charging by partially briquetting 30% of the coal charged to the coke oven (1). Alternatively coke oven productivity can be increased about 20% by carbonizing a partially briquetted industrial blend at faster heating rates before coke quality deteriorates below that of the conventional charge (2). Other investigations have shown that considerable amounts of poor and non-coking materials can be added to the briquetted portion of partially briquetted industrial type charges before coke quality deteriorates below that from conventional charges (3).

However, little has been learned in Canada about the behaviour of western Canadian coals when partially briquetted. These coals are exported primarily to Japanese coke makers, who use partial briquetting technology extensively for producing coke (4,5,6). The only previous partial briquetting investigation at CANMET using western Canadian coal showed a western Canadian high volatile (hv) coal to be the most effective of 4 hv coals at reducing the amount of low volatile coal required to make good metallurgical coke in partially briquetted binary hv-lv blends.

In this investigation medium (mv) and low volatile (lv) coals were each carbonized conventionally and then 30% partially briquetted at two coking rates to better understand their coking behaviour when 30% partially briquetted. Results of the study with the western Canadian hv coal are included.

EXPERIMENTAL PROCEDURES AND CONDITIONS

All carbonization tests were conducted in a CANMET moveable wall test oven which has a coking chamber 457-mm wide, 914-mm long, 914-mm high to the coal levelling door sill, and a charge capacity of 325 kg. The oven flue temperature is maintained at 1125°C by electrically heated globars and the heat is transferred to the coal charge through high density silica bricks

similar to those used industrially. Standard procedure is to charge the oven with coal containing 6% moisture and having a nominal pulverization level of 80 ± 5% minus 3 mm, resulting in a bulk density of the coal in the oven of about 744 kg/m^3 (dry basis). About 18 h is required to carbonize the charge to a centre temperature of 1000°C. Tests having faster coking rates used a flue temperature of 1225°C.

The matrix coal for 30% partially briquetted charges was prepared identically to that for conventional charging and was sampled for rheological and petrographic analyses. The coal or blend for briquetting was pulverized nominally to 90% minus 1 mm, mixed with 6% PDA asphalt (softening point/77°C) in a double-arm kneader-mixer heated to 100°C, and then briquetted in a double roll press which produced 30 x 30 x 18 mm pillow-shaped briquets. Briquet moisture at the time of charging was 1.2 - 1.8%. A flow diagram of CANMET's partial briquetting procedures is shown in Fig. 1.

After carbonization the coke is pushed from the oven, water quenched, dropped 3 m to simulate commercial coke handling, dried, screened, and tested for coke strength according to ASTM and JIS tumbler methods (7,8). Coke strength after reaction (CSR) tests were made on selected cokes (9).

RESULTS

Coal Properties

Tables 1 and 2 list chemical and petrographic properties of the lv and mv western Canadian coals used in this study and includes the hv coal investigated previously. All coals have relatively low fluidities for their rank; the mv and lv coals have high inert contents while the hv coal is rich in reactives.

Conventional and Partially Briquetted Studies of the Medium Volatile Coal Carbonized in the 460-mm wide Pilot Oven

The medium volatile coal was carbonized conventionally and 30% partially briquetted at two flue temperatures (coking rates) in the 460-mm wide moveable wall test oven; results are listed in Table 3.

Strength is the physical property of coke considered most important for good blast furnace operations. In North America, the ASTM stability factor obtained by cold tumbling of coke is considered the prime criterion for

determining coke strength; improvements to ASTM stability have been related to decreased blast furnace coke rates (10). For this investigation, Table 3 shows an average coke stability factor of 55.4 for the coke made from the conventionally charged mv coal carbonized at a flue temperature of 1125°C. Partially briquetting 30% of the coal and carbonizing at the same flue temperature improved the ASTM stability factor by 8.4 units to 63.8. Coke strength after reaction (CSR) and coke reactivity also improved significantly upon partial briquetting. The CSR result improved about 18 units from about 49 for the conventional charge to 67 for the partially briquetted charge. These values are more than acceptable by industry considering an earlier CANMET investigation indicated industrial coke had better CSR values than coke produced in the 460-mm oven (11). Substantial improvements were also observed in the ASTM hardness index and in the JIS tumbler indices upon partially briquetting the charge. Partial briquetting caused mean coke size to decrease although the amounts of coke breeze generated from the coke oven was reduced; the apparent specific gravity of the coke also increased. Coking pressures also increased upon partial briquetting to about 3.6 kPa.

It appears from Table 3 that increased flue temperatures decreased coke stability for conventionally or partially briquetted charges as was found previously with the commercial blend from a Canadian steel company (2). However, multiple linear analysis relating bulk density and flue temperature to ASTM stability suggested that stability was almost completely dependent on coal bulk density in the coke oven and that increased coking rates had little effect. Thus ASTM stability can be predicted for this coal according to the simple relationship:

$$\text{Stability} = 0.1083x(\text{bulk density}) - 25.8,$$

$$r = 0.97,$$

$$N = 8$$

$$SE = 1.05, \text{ and } F = 109;$$

as shown in Fig. 2. This equation may only apply when bulk density is changed from standard conditions by means of partially briquetting 30% of the charge; high bulk density conventional charges may behave differently. Coke produced at the higher flue temperature of 1225°C from high bulk density partially briquetted charges had substantially improved coke stability, by about 7.5 units, from that of the conventional charge. Partial briquetting of coke oven

charges at the higher flue temperature also increased coke hardness, the CSR values, and coking pressures from that of the conventional charges. The effect of the higher flue temperature alone caused mean coke size to decrease substantially, coke reactivity to decrease slightly, and may have improved ASTM hardness slightly. Little change occurred in the CSR results at higher flue temperature; coking pressures increased slightly at the higher flue temperatures to about 3.6 kPa.

Conventional and partially briquetted carbonization of low volatile coal

Table 4 lists results of the western Canadian low volatile coal carbonized conventionally and partially briquetted at low flue temperatures. A conventional charge at a high bulk density was also carbonized at 1125°C to investigate the changes in coke quality caused solely by increasing bulk density as opposed to increasing bulk density by partial briquetting.

Partial briquetting of this coal gave an impressive improvement to the ASTM coke stability factor as shown in Table 4. At a standard flue temperature of 1125°C for this oven the ASTM stability factor improved from an average of 46.8 units for the conventional charge to about 59.4 for the partially briquetted charge. At the 1225°C flue temperature stability improved slightly less, from 46.2 for the conventional charge to 57.5 for the partially briquetted charge. Figure 3 illustrates ASTM stability factors from Table 4 plotted as a function of bulk density and includes results obtained at different flue temperatures. The points on the figure show that changes in flue temperature had little effect on the ASTM stability factor for conventional charges; ASTM stability appeared to decrease slightly for partially briquetted charges at increased flue temperature. Multiple linear regression analyses relating ASTM stability to flue temperature and bulk density again indicated that stability was almost entirely independent of flue temperature. Figure 3 shows two relationships; the upper line represents the improvement in stability caused by increasing bulk density through partially briquetting this lv coal charge. The lower line represents only the conventional charges and shows the improvement in ASTM stability caused by increasing bulk density through adjustment of charge moisture. Thus, the finer pulverization of the coal in the briquets and the addition of the PDA pitch material or just the effect of the coal being briquetted improved coke stability more than would be expected from just bulk density considerations.

The JIS tumbler indices from Table 4 also showed that, partial briquetting of the lv coal gave larger improvements to tumbler indices than were expected from just the increased coal bulk densities. Unlike the results from ASTM stability, the JIS indices improved for cokes made at the higher flue temperatures for both conventionally and partially briquetted charges. The ASTM hardness factor, to a lesser extent followed a similar trend. Mean coke size decreased at the higher flue temperature as expected, for both the conventional and partially briquetted charges. The coke size, however, was larger from partially briquetted charges than from the conventional charges as indicated by both mean coke size and the amount of plus 51 mm coke, Table 4. This result had not been found previously for any of the coals investigated at CANMET. Compared to conventional charges, the amount of coke breeze from partially briquetted charges was markedly improved even at similar coal bulk densities. This contributes significantly to the larger mean coke size. At higher temperature the amount of coke breeze generated from the pilot oven improved (decreased) even further.

The CSR improved markedly from a very low value for the conventional charge to 38.2 units for the partially briquetted charge carbonized at 1225°C. Although this result is still considered low by industrial criteria, previous work at CANMET has shown that coke from the 460-mm test oven has CSR values considerably lower than coke from an industrial oven (11).

Quite large coke oven wall pressures were generated, not unexpectedly, for the lv coal when coal bulk density in the test oven was increased by partially briquetting 30% of the charge. Although care must be taken to ensure safe wall pressures, the very large improvements to coke quality when carbonizing this coal 30% briquetted suggested it should be an excellent blending coal for partially briquetted charges. Further investigations of this nature are warranted.

Conventional and partially briquetted carbonization of high volatile coal

This coal was used in an earlier partial briquetting study and was found the most effective of 4 hv coals at reducing the amount of Appalachian lv coal required to make high quality metallurgical coke from partially briquetted binary hv-lv blends. By partially briquetting this hv coal coke quality improved from that of the conventional charge evidenced by the improvements to ASTM and JIS tumbler indices, the amount of coke breeze, and the ASG

of the resultant coke. The improvement to coke quality was generally less than for the medium and low volatile coals discussed earlier. However, bear in mind that all high volatile coals (from Appalachia) investigated previously at CANMET actually had coke quality (as measured by the stability factor) deteriorate or remain unchanged upon partial briquetting. Consequently this western Canadian hv coal appears to be a superior coal for using in blends of partially briquetted charges, particularly in view of the low coking pressures associated with this coal.

DISCUSSION AND CONCLUSIONS

A marked improvement in coke quality from that of conventional charges was found for the three partially briquetted western Canadian coals carbonized in CANMET's 460-mm coke oven. Major improvements were found in coke tumbler indices, ASG, breeze and coke reactivity.

Partially briquetting the medium volatile and low volatile coals in this study improved ASTM stability by about 8 and 12 units respectively while the stability for the high volatile coal improved by about one unit. For all Appalachian type coals used in an earlier CANMET study, ASTM coke stability improved negligibly by partial briquetting single coals and by less than about 7 units for blends of these coals. The improvement to the ASTM stability factor of coke made by partial briquetting western Canadian coals appeared to increase with increased rank and decreased caking properties of the coal. The latter parameter may be of more significance in view of earlier work with one high rank Appalachian coal which gave no improvement upon partial briquetting. However, additional data from partially briquetted coals is required to verify such influences as coal rank and caking properties on coke quality.

ASTM coke stability improvements caused by partial briquetting can be attributed mainly to increased bulk density of partially briquetted charges. However, other factors also play a role (e.g., finer pulverization and binder) as evidenced by the better coke stability for a partially briquetted charge than for a conventional charge having similar bulk density. Carbonization at a higher flue temperature of partially briquetted medium and low volatile coals caused only very minor deteriorations to coke quality from that produced at a lower temperature; thus, coke oven productivity might be improved substantially without any large loss in coke quality for partially briquetted charges.

Thus preliminary results from partially briquetted coke oven charges of western Canadian coals indicated they have excellent potential for making coke. Because cokemakers generally blend several coals together to make coke, future partial briquetting investigations should include:

- addition of various ranks of western Canadian high inert coals to Appalachian type blends similar to that used by the Canadian steel industry. Partially briquetted blends of this type may allow steel companies to improve coke quality without having excessive coking pressures.
- blending of several western Canadian coals as a means of producing high grade metallurgical coke.
- doing commercial trials with one or more of the above blends.

Blend components should be carbonized conventionally and partially briquetted to determine the effects of petrographic and rheological coal properties on coke quality from partially briquetted charges.

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Table 1 - Coal properties of low, medium and high volatile western Canadian coals

		LV Coal	MV Coal	HV Coal
Volatile matter	(db) %	17.8	19.3	32.0
Ash	(db) %	7.4	10.2	5.4
Carbon	%	84.4	81.7	81.4
Hydrogen	%	4.2	4.3	5.2
Sulphur	%	0.40	0.25	0.49
Nitrogen	%	1.1	1.4	1.6
Gieseler Plasticity				
Maximum Fluid Temp	°C	479	471	449
Solidification Temp	°C	492	491	478
Melting Range	°C	15	37	59
Maximum Fluidity	dd/m	1.3	3.5	339
Dilatation				
Maximum Contraction/Temp	°C	24/479	27/474	28/431
Maximum Dilatation/Temp	°C	-24/-	2/485	9/461
Free Swelling Index		7	5 1/2	7 1/2
Pulverization (% passing 3 mm)		89.9	91.6	84.6
Hardgrove Index		97	84	-

Table 2 - Petrographic properties

	LV Coal	MV Coal	HV Coal
Vitrinite Types %			
V-7	-	-	0.6
V-8	-	-	11.4
V-9	-	-	40.1
V-10	-	-	10.2
V-11	-	-	1.3
V-12	-	13.93	-
V-13	-	22.45	-
V-14	4.95	8.09	-
V-15	24.71	0.45	-
V-16	30.26	-	-
V-17	1.85	-	-
Maceral analysis %			
Vitrinite	61.76	44.93	63.6
Semi-fusinite	26.00	40.02	18.2
Exinite	0.00	0.00	5.0
Micrinite	2.11	2.27	3.6
Fusinite	6.04	7.17	6.6
Mineral matter	4.09	5.61	3.0
Mean relflectance	1.59	1.34	0.94
Balance index	3.56	2.78	0.83
Strength index	7.16	5.56	3.56
Stability index	52.81	51.66	47.0

Table 3 - Results of investigation of western Canadian medium volatile coal, carbonized conventionally and partially briquetted at two flue temperatures in 460-mm wide movable wall oven

		Conv	1125°C	PB	1125°C	Conv	1225°C	PB	1225°C
Description									
Moisture in charge	%	5.9	6.0	4.6	4.6	6.0	6.0	4.6	5.9
Carbonization Conditions									
Calc. charge dry bulk density in oven	kg/m^3	757	781	821	821	739	728	814	800
Flue temp control		1125	1125	1125	1125	1225	1225	1225	1225
Charge push (Centre temp:Soak time)	°C/h	1016	1007	993	985	1116	1116	-	1080
Carbonization Results									
Gross coking time (at Push)	h:min	18:50	18:50	19:55	20:05	17:35	17:35	17:30	17:30
Final centre temp	°C	1016	1007	993	985	1116	1116	-	1080
Time to 900°C	h:min	16:40	16:50	18:15	18:20	12:35	13:35	15:09	14:40
Maximum wall pressure	kPa	0.14	0.28	2.7	3.3	0.41	1.24	3.2	3.6
Coke yield actual		77.8	77.0	78.1	79.1	76.7	76.3	78.8	78.4
Screen Analysis of Coke									
(cum % retained on)									
102 mm sieve		5.6	2.9	3.6	2.5	1.7	0.0	0.3	-
76 mm sieve		21.5	23.1	17.2	15.4	7.7	9.5	6.7	7.1
51 mm sieve		60.9	64.5	55.3	55.3	41.7	47.3	38.3	40.3
30 mm sieve		82.3	83.3	82.4	80.8	72.9	78.2	71.9	74.4
25 mm sieve		92.3	92.3	94.8	94.7	92.4	92.8	93.5	93.5
19 mm sieve		93.3	93.1	95.8	95.6	94.1	94.3	95.6	95.3
13 mm sieve		93.8	93.7	96.4	96.2	95.1	95.1	96.2	96.1
Percentage 13 mm (breeze)		6.2	6.3	3.6	3.8	4.9	4.9	3.8	3.9
Mean coke size	mm	58.4	59.4	56.9	55.6	49.7	51.6	48.7	49.3
Coke Apparent Specific Gravity		0.974	0.973	0.970	0.987	0.958	0.957	0.989	0.982
ASTM Coke Tumbler Test									
Stability factor		56.0	54.8	63.8	63.7	53.0	53.8	60.4	61.5
Hardness factor		62.8	60.3	70.8	71.5	62.4	62.3	72.3	72.7
JIS Coke Tumbler Test									
(cum % retained on)									
30 revs 15 mm sieve		92.3	92.0	93.3	94.4	90.2	91.8	94.4	93.3
150 revs 15 mm sieve		80.6	79.4	83.7	85.0	77.7	79.1	84.8	83.5
CSR Test									
Reactivity		25.6	-	22.9	-	22.8	-	19.6	-
Coke strength		49.0	-	66.9	-	48.9	-	66.6	-

Table 4 - Results of investigation of western low volatile Canadian coal carbonized conventionally and partially briquetted at two flue temperatures in 460-mm movable wall oven

Description and Type of charge	Conv	Conv 1125°C	PB	PB 1125°C	Conv 1225°C	PB 1225°C	Conv 1125 with high BD
Moisture in charge	5.9	5.6	4.7	4.6	6.1	4.6	3.0
Carbonization Conditions							
Calc. charge dry bulk density in oven kg/m^3	718	723	787	785	715	794	834
Flue temp control	1125	1125	1125	1125	1225	1225	1125
Charge push (Centre temp:Soak time) °C/h	1016	1021	1018	1004	1121	1068	995
Carbonization Results							
Gross coking time (at Push) h:min	18:15	17:40	19:15	19:05	18:35	17:10	19:40
Final centre temp °C	1016	1021	1018	1004	1121	1068	995
Time to 900°C centre temp h:min	16:35	16:10	17:37	17:35	15:10	15:18	17:50
Maximum wall pressure kPa	3.0	3.0	25.7	22.7	4.4	26.1	25.2
Coke yield actual	75.3	75.9	78.7	78.5	78.3	80.3	76.3
Screen Analysis of Coke							
(cum % retained on)							
102 mm sieve	2.3	3.4	4.6	2.3	1.7	0.6	6.8
76 mm sieve	18.5	18.2	20.7	14.1	11.3	9.7	24.0
51 mm sieve	57.8	56.4	60.0	58.9	44.7	46.8	62.3
38 mm sieve	70.5	71.0	80.9	81.7	68.8	72.2	84.6
25 mm sieve	77.0	77.8	91.2	91.7	76.0	93.1	91.2
19 mm sieve	78.3	79.1	92.9	82.7	77.2	94.5	91.8
13 mm sieve	79.1	79.8	93.4	93.5	78.2	95.1	92.5
Percentage 13 mm (breeze)	20.9	20.2	6.6	6.5	21.8	4.9	7.5
Mean coke size mm	51.3	51.6	57.9	55.6	46.2	51.6	60.1
Coke Apparent Specific Gravity	0.847	0.853	0.899	0.904	0.860	0.891	0.900
ASTM Coke Tumbler Test							
Stability factor	45.0	47.5	59.2	59.6	46.2	57.5	57.6
Hardness factor	49.3	52.7	65.4	64.1	53.8	65.9	62.4
JIS Coke Tumbler Test							
(cum % retained on)							
30 revs: 15 mm sieve	31.8	42.8	39.8	30.0	21.5	17.9	34.9
25 mm sieve	80.9	80.6	91.9	89.6	80.7	81.8	90.6
15 mm sieve	83.0	82.4	94.5	93.3	85.0	94.2	92.8
150 revs: 50 mm sieve	9.1	10.2	17.4	12.8	2.5	9.9	14.8
25 mm sieve	62.5	62.1	9.0	25.3	61.6	77.0	76.5
15 mm sieve	65.8	65.3	83.3	81.8	69.1	84.0	80.7
CSR Test							
Reactivity	33.5		35.4		37.6	36.9	40.1
Coke strength	9.9		34.8		9.8	38.2	27.2

Table 5 - Results of western Canadian high volatile coal carbonized conventionally and partially briquetted in 460-mm wide test oven

	Conv charge	Partially briq charge
Charge Properties		
Moisture in charge	6.0	4.8
Carbonization Conditions		
Calc. charge dry bulk density in oven .....kg/m^3	72.7	80.3
Flue temp control	1125	1125
Carbonization Results		
Gross coking time (at Push) .....h:min	19:30	21:00
Final centre temp ..... °C	1000	940
Time to 900°C centre temp .....h:min	16:15	18:15
Maximum wall pressure ..... kPa	1.8	1.72
Coke yield actual	67.4	69.5
Screen Analysis of Coke		
(cum % retained on)		
102 mm sieve	1.2	4.4
76 mm sieve	16.4	17.9
51 mm sieve	58.6	56.7
38 mm sieve	84.0	81.8
25 mm sieve	93.7	94.2
19 mm sieve	95.0	95.6
13 mm sieve	95.9	96.7
Percentage -13 mm (breeze)	4.1	3.3
Mean coke size ..... mm	56.5	58.4
Coke Apparent Specific Gravity	0.81	0.86
ASTM Coke Tumbler Test		
Stability factor	45.9	47.6
Hardness factor	58.8	62.1
JIS Coke Tumbler Test		
(cum % retained on)		
30 revs: 15 mm sieve	90.6	92.5

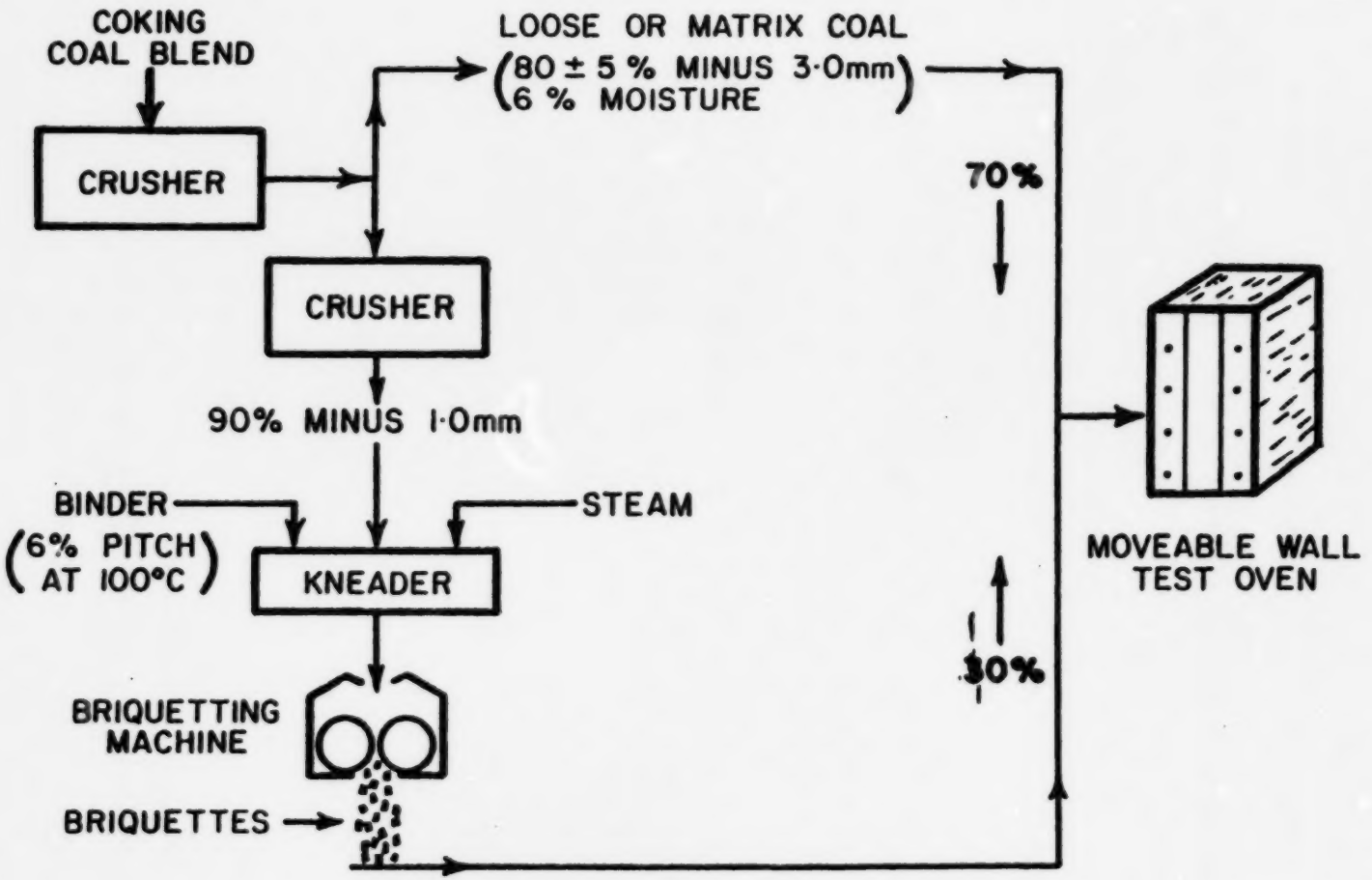

Figure 1. FLOW DIAGRAM OF CANMETS PARTIAL BRIQUETTING PROCEDURE

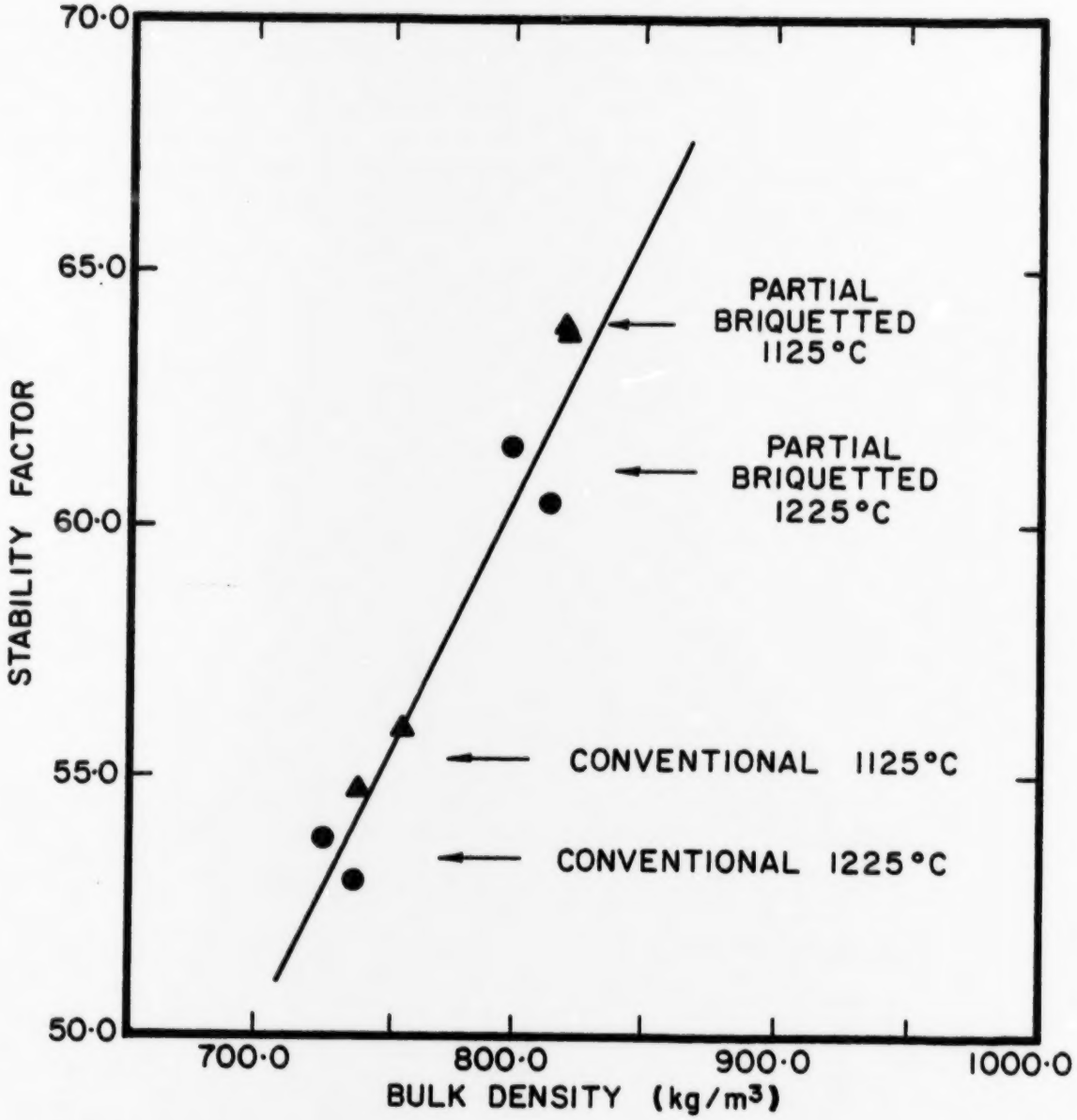

Fig. 2 Effect of changes in the coal bulk density in the 460-mm coke oven on the coke ASTM stability factor for coke made from western Canadian medium volatile coal by conventional and partially briquetted charges.

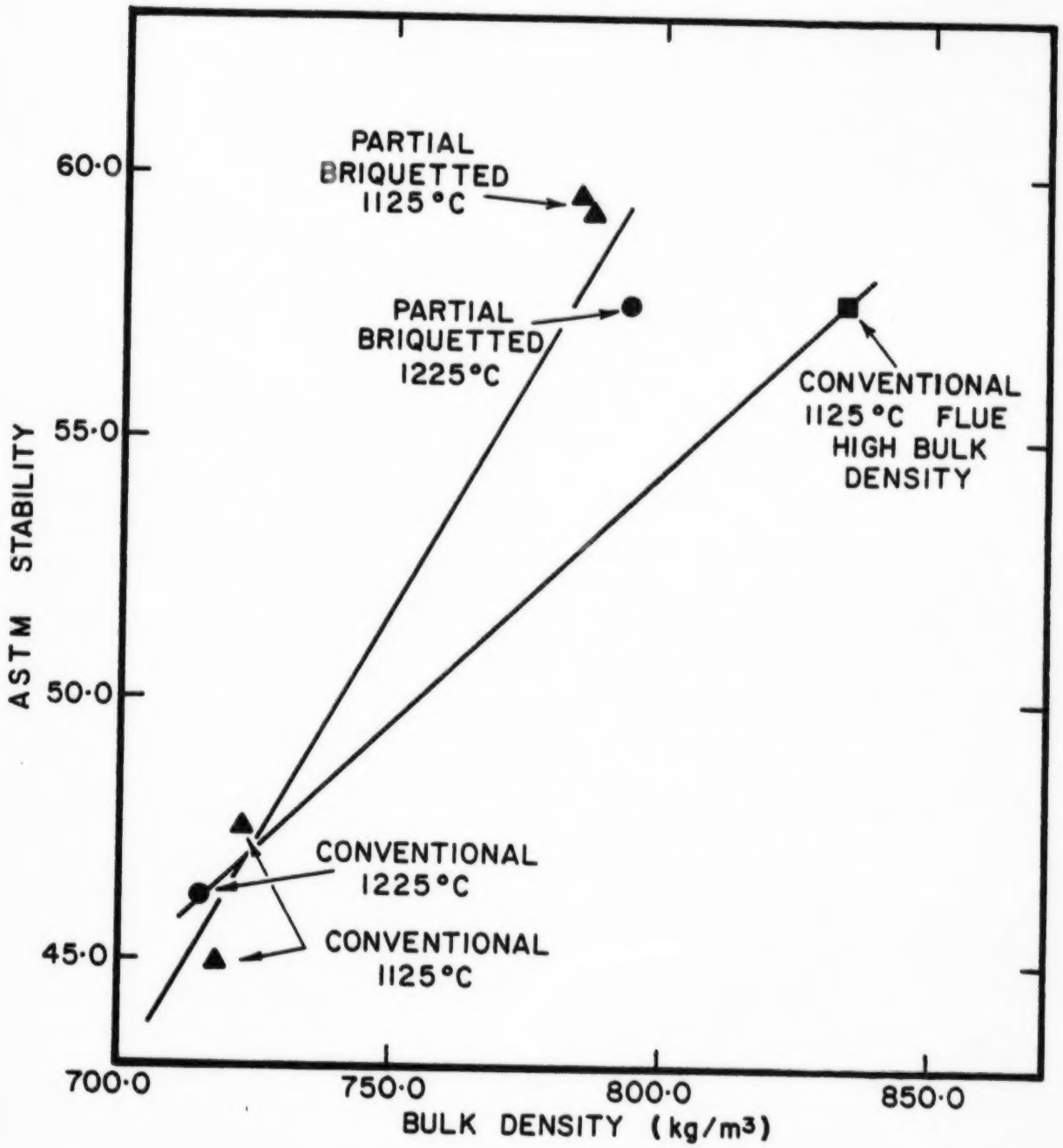

Fig. 3 Effect of changes in the coal bulk density in the 460-mm test oven on the ASTM stability factor of coke made from western Canadian low volatile coal by conventional and partially briquetted charges.